

In Situ and Satellite Sea Surface Temperature (SST) Analyses

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1. PROJECT SUMMARY

The purpose of this project is to focus on improvements to the climate-scale sea surface temperature (SST) analyses produced at NOAA as described by Reynolds et al. (2002) and Smith and Reynolds (2004). This effort is designed to support the development of an ocean climate observing system. The major effort has focused on the optimum interpolation (OI) analysis which includes a separate step to correct any large scale satellite biases relative to in situ (ship and buoy) data. A new version has been developed (Reynolds, et al., 2006), henceforth called the daily OI, which has improved the spatial grid resolution from 1° to $1/4^\circ$ and the temporal resolution from weekly to daily. The daily OI was designed use multiple satellite data sets as well as in situ data. At present there are two version of the daily OI. One product uses infrared satellite data from the Advanced Very High Resolution Radiometer (AVHRR). The second product uses AVHRR and microwave satellite data from the Advanced Microwave Scanning Radiometer (AMSR) on the NASA Earth Observing System. The AVHRR-only product began in January 1985 and the AMSR+AVHRR product began in June 2002 when AMSR data became available. Both products include a large-scale adjustment of satellite biases with respect to the in situ data. Two products are needed because there is an increase in signal variance when AMSR became available due to its near all-weather coverage.

Additional efforts have been carried out to improve the Extended Reconstruction SST (ERSST) analysis of Smith and Reynolds (2004). This analysis presently uses in situ data and begins in 1854. The reconstructions were produced from two analyses. First the low frequency, or decadal-scale component, of the anomaly was analyzed using averaging and filtering of the available anomalies. The analyzed low frequency signal was subtracted from the anomalies and the residual high-frequency signal was analyzed. The high frequency analysis was performed by fitting the observed high frequency anomalies to a set of large-scale spatial-covariance modes. The new version is tuned using climate general circulation model (CGCM) output, which reduces the low frequency analysis damping. The effects of several other problems will also be corrected.

One of the important goals of the Sustained Ocean Observing System for Climate is to improve the SST accuracy over the global ocean. Because of the high coverage of satellite data, in situ data used in the analysis tends to be overwhelmed by satellite data. Thus, the most important role of the in situ data in the analysis is to correct large-scale satellite biases. Simulations with different buoy densities showed the need for at least two buoys on a 10° spatial grid. This will ensure that satellite biases do not exceed 0.5°C . Using this criterion, regions were identified where additional buoys are needed, and a metric was designed to measure the adequacy of the present observing system. Improved bias correction methods now being developed may reduce the needed sampling.

Richard W. Reynolds serves on the Ocean Observation Panel of Climate (OOPC) and the Global Ocean Data and the Assimilation Experiment High Resolution Surface Temperature Pilot Project (GHRSSST-PP) Science Team. Members of both groups consist of well-known national and international scientists. All work presented here follows the Ten Climate Monitoring Principles.

2. FY 2006 PROGRESS

2.1 The Daily OI Analyses

During FY2006, two new products have been developed: the AVHRR-only daily OI from January 1985 to present and the AMSR+AVHRR daily OI from June 2002 to present. As described in Reynolds et al. (2006) both analyses use in situ data and use a new satellite bias correction based on empirical orthogonal teleconnections (EOT) functions (van Den Dool et al. 2000). Both products are presently available via FTP: (<ftp://eclipse.ncdc.noaa.gov/pub/OI-daily/>), TDS: (<http://nomads.ncdc.noaa.gov:8085/thredds/catalog.html>) and LAS: (<http://nomads.ncdc.noaa.gov:8085/las/servlets/dataset>). A web server is under development.

To evaluate the new daily OI analyses, the input data and the analyses were compared with each other and with other analyses. For this comparison, the weekly OI of Reynolds et al. (2002), henceforth referred to as the OI version 2 (OI.v2) was used. As mentioned above the OI.v2 uses AVHRR satellite data and in situ data and is performed weekly on a 1° spatial grid from November 1981 to present. An additional analysis was obtained from the National Center for Environmental Prediction daily Real Time Global SST (RTG_SST) analysis (Thiébaux et al., 2003). The RTG_SST analysis uses the same data used in the OI.v2. However, the RTG_SST is run daily beginning on 30 January 2001 on a 1/2° grid and uses smaller spatial error correlation scales than those used in the OI.v2.

Chelton and Wentz (2005) compared these two analyses with AVHRR and AMSR data with particular focus on 6 regions with strong SST fronts, including the Gulf Stream. The Gulf Stream gradients are presented in Fig. 1 following Chelton and Wentz with the addition of the two new daily OI analyses. The figure shows the magnitude of the 3-day mean Gulf Stream SST gradients centered on 1 October 2003. The AVHRR data panel shows high resolution details in cloud-free regions, although the coverage for AVHRR data is less than half of the possible number of ocean grid points. The AMSR data panel shows smoother details because of the coarser footprint but with the expected better coverage. The analyses fill in the missing AMSR and AVHRR data gaps with different smoothing. In particular, note the region of missing AMSR data due to precipitation contamination between 35°N and 45°N along 60°W. The OI.v2 is heavily smoothed as reported by Chelton and Wentz. The RTG_SST and AVHRR OI are similar, showing much more detail. Here the RTG_SST slightly smoother than the AVHRR OI. The best analysis resolution is shown by the AMSR+AVHRR analysis, which is similar to the AMSR data in most of the offshore regions. All statistical parameters in the daily OI are the same for both products. Thus, the improvement in the AMSR+AVHRR analysis is due to the better AMSR coverage.

1 October 2003

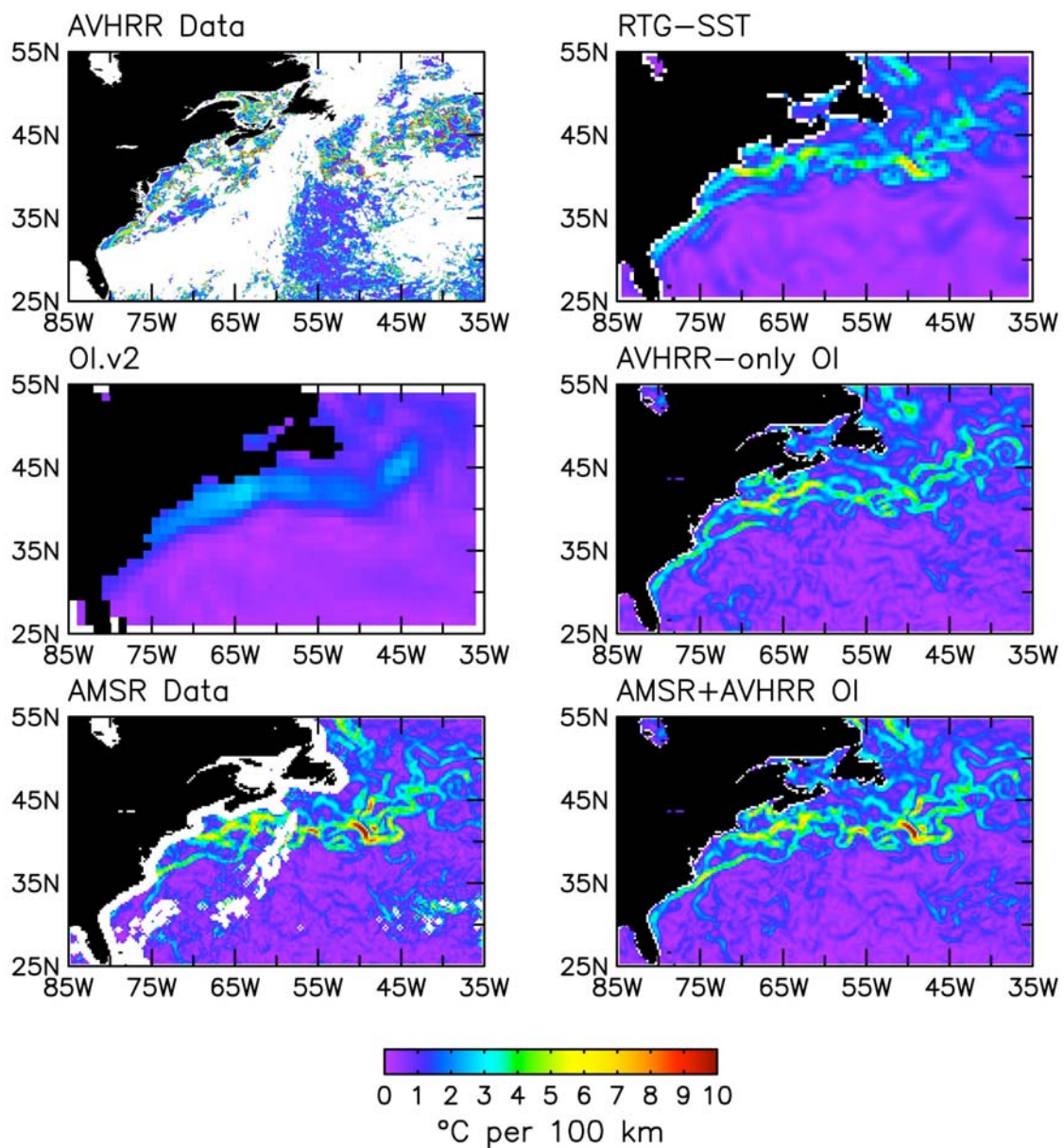


Figure 1. Three-day averages of SST gradient magnitudes for analyses and data centered on 1 October 2003 for the Gulf Stream region. The data products are AVHRR and AMSR. The analyses are: OI.v2, RTG_SST and the daily OI for AVHRR-only and AMSR+AVHRR.

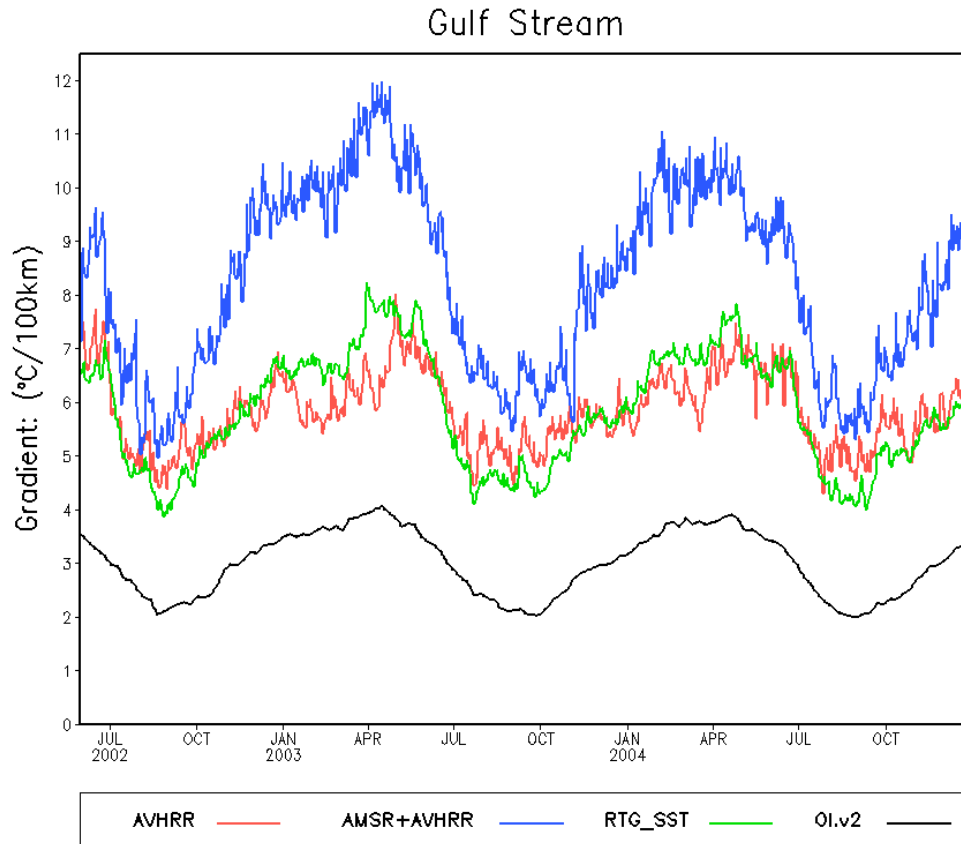


Figure 2. Analysis SST gradient index (see text) for the Gulf Stream region for 1 June 2002 - 31 December 2004. The analyses are the OI.v2, the RTG_SST and the daily OI using AVHRR-only and AMSR+AVHRR.

To better examine the gradients over time, gradient indices were computed. The index for the Gulf Stream was computed from the daily magnitude of the SST gradients from June 2002 through December 2004 for daily OI runs: AVHRR-only and AMSR+AVHRR and for the OI.v2 and RTG_SST analyses. For the Gulf Stream the maximum gradient value was determined along lines of longitudes from 70°W - 40°W between 35°N and 50°N ; these maximum values were then averaged over longitude. The daily index is shown for the Gulf Stream in Fig. 2. The results show that the OI.v2 index is much lower than the others as expected from Fig. 1. Also as expected, the AVHRR-only and the RTG_SST indices are generally quite similar. Perhaps the most interesting difference occurs between the AVHRR-only and AMSR+AVHRR gradient indices. These indices are similar in August and September with the AMSR+AVHRR gradient index only slightly stronger. The differences gradually increase from September to roughly March and then decrease again to the August minimums. In winter the AMSR+AVHRR gradient index is almost double the AVHRR-only index. The results show that the seasonal cycle of the index is under represented by AVHRR alone, because cloud cover tends to be more pervasive in winter. Indices for the Kuroshio region (not shown) show a similar seasonal cycle although both the average and seasonal amplitude are weaker. The Kuroshio index is again stronger for the AMSR+AVHRR product in winter because of reduced AVHRR coverage due to cloud cover.

OI Daily SST: 2003–2005

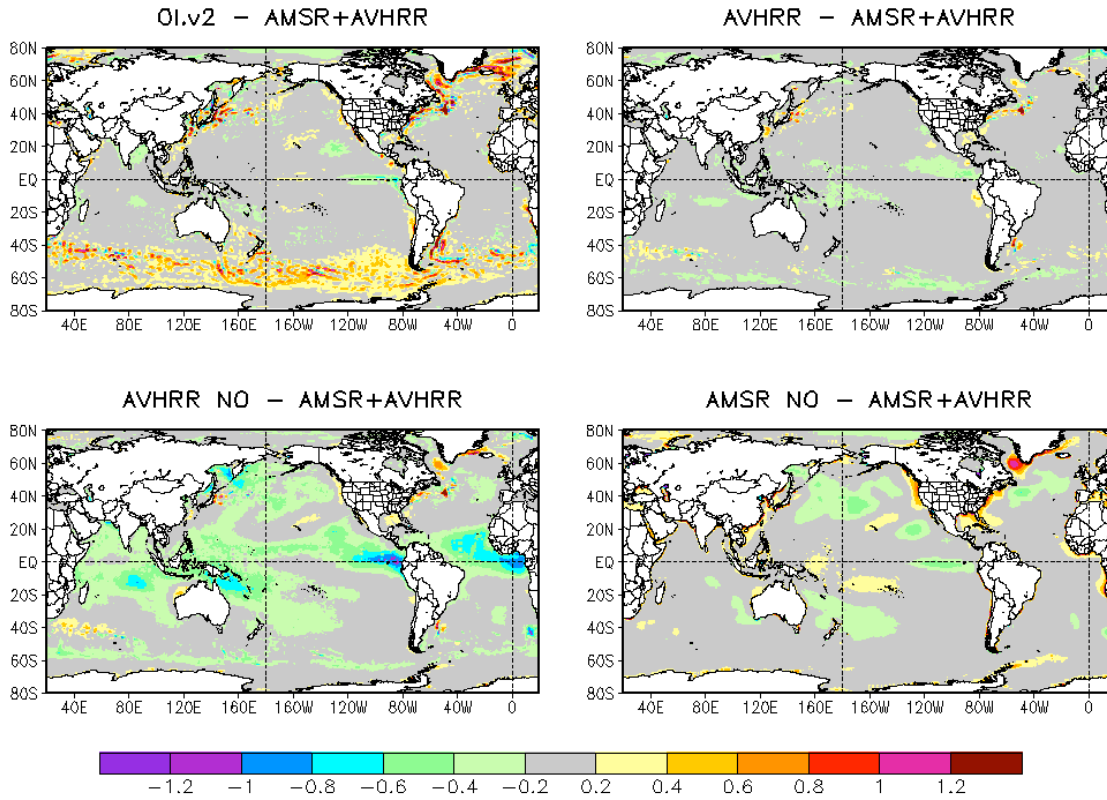


Figure 3. Average analysis differences for 2003-2005 with respect to the daily OI AMSR+AVHRR with bias correction. The analyses compared with bias correction are the AVHRR-only daily OI and the OI.v2 (top row). The analyses without bias correction are the AVHRR-only and the AMSR+AVHRR daily OI (bottom row). "No" in the title indicates no bias correction.

The large-scale biases for the January 2003 - December 2005 period are now examined where the AMSR+AVHRR daily OI analysis is used as a reference. Two special AVHRR-only and AMSR+AVHRR daily OI analyses were made without satellite bias correction. The average difference with respect to the AMSR+AVHRR was computed for this period for the OI.v2, the AVHRR-only daily OI (with and without bias correction) and the AMSR+AVHRR daily OI without bias correction. For this comparison the OI.v2 was linearly interpolated to the daily OI grid. The average difference is shown in Fig. 3 where "NO" indicates an analysis without bias correction. The OI.v2 (top left in Fig. 3) shows that the biggest difference with respect to the AMSR+AVHRR daily OI occurs between 60°S and 40°S, with largest values in the Pacific east of the dateline. This is the region with sparse in situ data and thus, the true bias is not well known. Many of the other differences in the western boundary current regions (e.g., in the Gulf Stream and Kuroshio) and the eastern Pacific equatorial region are due to the increased resolution of the daily OI. The AVHRR-only OI with bias correction (top right) shows some residual biases with respect to the AMSR+AVHRR daily OI primarily along the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone, SPCZ), a reminder that

residual biases can survive the bias correction step if the biases persist. The bottom row of Fig. 3 shows the biases in the OI analyses without satellite bias correction. The AVHRR-only OI analysis without bias correction (bottom left) shows the largest biases with respect to the AMSR+AVHRR analysis with bias correction. The biases are especially evident tropical oceans. Comparison with the AVHRR-only OI analysis with bias correction (top right) shows the necessity of the bias correction. The AMSR+AVHRR OI analysis without bias correction (bottom right) with respect to the AMSR+AVHRR analysis with bias correction shows smaller long-term biases although some biases remain.

2.2 The Historic ERSST Analysis

The monthly ERSST analysis initially used a low frequency analysis on a 15-year period to begin the analysis. The reconstructions were designed to analyze signals supported by the historical sampling, with damping of anomalies when sampling was insufficient to analyze the climate-scale signal. Deciding how much sampling was sufficient was based on the data themselves and on estimates of spatial and temporal scales of the low frequency components. In the Smith and Reynolds (2004) these decisions were conservative, to ensure that data noise would not contaminate the analysis in sparse-sampling periods. A disadvantage of such conservative decisions is that they may lead to overly damped analyzed anomalies early in the historical record.

To evaluate these decisions, simulated SST anomaly data from the Geophysical Fluid Dynamics Laboratory (GFDL) Climate Model 2.1 (CM2.1) were used. The low frequency analysis was tuned by use of different parameters. The test analyses were computed using the data with simulated random errors and data gaps determined from the observations. They were compared to a full analysis, computed using data with no random error and no data gaps. Tuning was done to minimize the mean-squared error of the test analyses relative to the full analysis.

The influence of changing these parameters is shown in the merged low frequency average between 60°S and 60°N in Fig. 4. In the figure, "Full" indicates the fully sampled data. After about 1930 there is little damping with respect to the "Full" analysis in any of the estimates computed using historical sampling. In the earlier period, most damping occurs using the default parameter settings, labeled "Old". The damping is greatly reduced using the new tuned parameters, labeled "New". With the improved tuning there is little damping after about 1875, but before that year there is still damping due to sparse sampling. In the next version of ERSST the "New" tuning parameters for the low frequency analysis will be used.

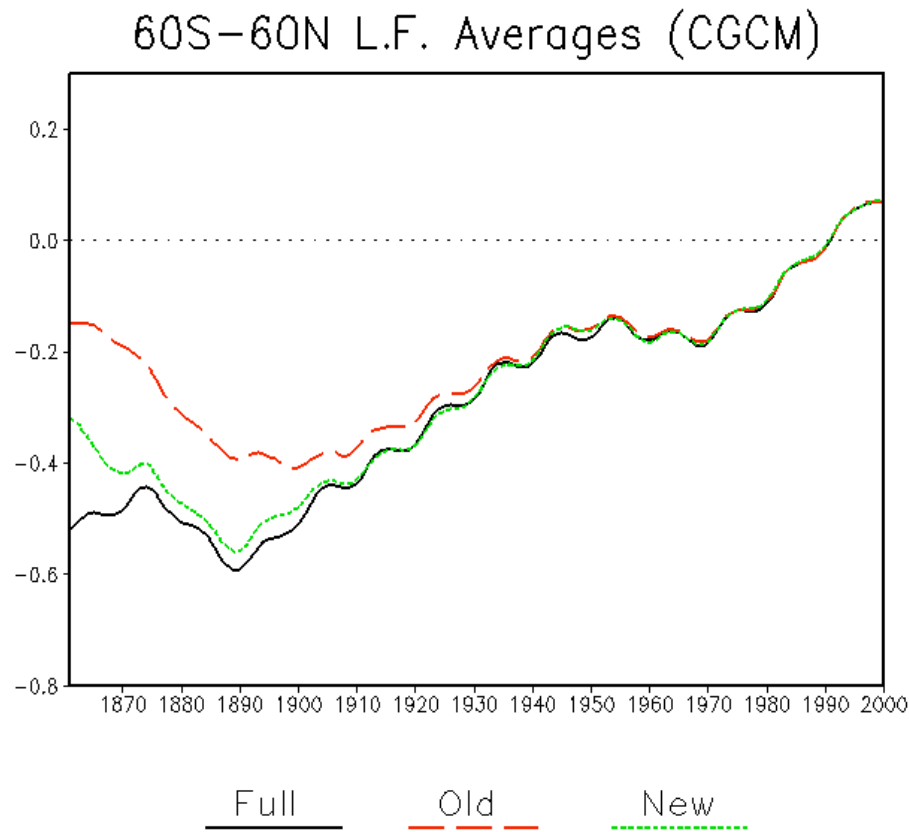


Figure 4. Low frequency analysis using the fully-sampled data (Full), and the historically sampled data using the operational parameter settings (Old), and the newly tuned settings (New). Random error is excluded from the Full data and included in the historically-sampled data used for the test Old and New analyses.

2.3 Design of an In Situ SST Network to Improve the SST Analysis

During the preceding years, an in situ network to correct "potential satellite bias errors" was determined using simulated biased satellite retrievals and simulated unbiased buoy data. The maximum "potential satellite bias error" was selected to be 2°C as a worse case. Thus, the "potential satellite bias error" would be 2°C if there were no in situ data to correct the bias. The data density of the present in situ network was evaluated to determine where more buoys are needed. These buoys could be either moored or drifting. However, because of the high cost of moored buoys they will be assumed to be drifters. To reduce the potential satellite bias to below 0.5°C , a buoy density of about 2 buoys/ 10° grid is required. The present in situ SST observing system was evaluated to define an equivalent buoy density allowing ships to be used along with buoys according to their random errors. These figures are operationally produced seasonally and are used to guide surface drifting buoy deployments. For more details see Zhang et al (2006).

References

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- Copies of Zhang et al. (2006) and Reynolds et al. (2006) will be attached to this report.**